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RECTAL INSUFFLATION OF HYDROGEN GAS

AN INFALLIBLE TEST IN THE DIAGNOSIS OF VIS-
CERAL INJURY OF THE GASTRO-INTESTINAL
CANAL IN PENETRATING WOUNDS
OF THE ABDOMEN.

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presented by the author.

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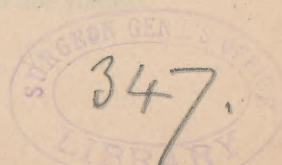
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RECTAL INSUFFLATION OF HYDROGEN GAS AN INFALLIBLE TEST IN THE DIAGNOSIS OF VISCERAL INJURY OF THE GASTRO-INTESTINAL CANAL IN PENETRATING WOUNDS OF THE ABDOMEN.

The operative treatment of penetrating wounds of the abdomen complicated by visceral injury of the gastro-intestinal canal is now sanctioned by the best surgical authorities, and may be considered as a well established procedure, based as it is upon the results of experimentation and clinical experience. A visceral wound of the stomach or any portion of the intestinal canal sufficient in size to give rise to extravasation into the peritoneal cavity must be looked upon as a mortal injury unless promptly treated by abdominal section. A number of well authenticated cases are on record where a wound in the stomach or the large intestine healed and the patients recovered without the intervention of surgery, but these instances are so few that, practically, the force of the preceding statement remains unimpaired. After a careful study of an immense clinical material Otis came to the important conclusion that gunshot injuries of the small intestines under the old expectant treatment without exception resulted in death, and this is a sufficiently cogent argument in favor of their treatment by laparotomy as affording the only chance of recovery.

The great difficulty that presents itself to the surgeon in the absence of positive symptoms is the differential diagnosis between a simple penetrating wound and a penetrating wound complicated by in-



gery. This picture is not overdrawn. Such cases have happened and will happen again. It is apparent that if some infallible diagnostic test could be applied in cases of penetrating wounds of the abdomen which would indicate to the surgeon the presence or absence of visceral lesions of the gastro-intestinal canal the indication for aggressive treatment would become clear and the medico-legal responsibility of the operator would be reduced to a minimum. As we can never expect by a study of symptoms or by the ordinary physical examination to fill this gap, I was induced to search for some reliable test which in such cases should prove that the penetrating bullet or instrument had injured the gastro-intestinal canal. It occurred to me that a wound in the stomach or intestine should be sought for in some such way as the plumber locates a leak in a gas-pipe. The first object to be accomplished was to prove the permeability of the entire gastro-intestinal canal to inflation of air, and the next step was to find some innocuous gas which when inflated would escape from the intestinal wound into the peritoneal cavity, and from there through the external wound, where its presence could be proved by some infallible test.

I. PERMEABILITY OF THE ILEO-CÆCAL VALVE TO RECTAL INSUFFLATION OF AIR OR GAS.

A great deal has been said and written in reference to the permeability of the ileo-cæcal valve to injections of fluids into the rectum or to the insufflation of air or gases. The majority of those who have studied this subject clinically or by experiment make the positive assertion that the ileo-cæcal valve is perfectly competent and effectually guards the ileum against the entrance of both fluids and gases forced into the rectum, while others insist that it is permeable only in exceptional cases, and only a few claim that its resistance can be

overcome by a moderate degree of pressure. Heschl (*Zur Mechanik der diastaltischen Darmperforationen Wiener Med. Wochenschrift*, No. 1, 1881) made a number of experiments and satisfied himself that the ileo-cæcal valve serves as a safe and perfect barrier against the entrance of fluids from below. In testing the resisting power of the coats of the intestine he found that the serous coat of the colon gave way first to overdistension, while the remaining tunics yielded subsequently to a somewhat slighter pressure. The small intestine of a child on being subjected to overdistension ruptured first on the mesenteric side, the place where acquired diverticular are found. Bull (*Virchow's Jahresbericht*, 1878, B. 11. S. 205) has found that in the adult one litre of water injected by the rectum will reach the cæcum, but that the entire capacity of the large intestine is from 4 to 5 litres. He is of the opinion that in the living body fluid cannot be forced beyond the ileo-cæcal valve, although ancient and modern experimenters claim to have succeeded in the cadaver. He affirms that when the rectum is distended by air the ileo-cæcal valve is rendered incompetent and the air passes into the small intestines.

Cantani (*Virchow's Jahresbericht*, 1879, B 11 S, 180) is a firm believer in the permeability of the ileo-cæcal valve to fluid rectal injections. In one instance he treated a case of coprostasis by an injection of a litre and a half of oil per rectum, and an hour later a part of the oil was ejected by vomiting. He advises that the intestinal tract above the ileo-cæcal valve should be utilized as an absorbing surface in cases requiring rectal alimentation, and when in a diseased condition should be treated by topical applications.

Behrens (*Ueber den Werth der Künstlichen Auftreibung des Dickdarmes mit Gasen u. Flüssigkeiten. Goettingen. Dissertation. 1886*) concluded from his experiments that it required the insufflation per

rectum of one and one-eighth litres of air to reach the ileum through the ileo-cæcal valve. In his experiments he had no difficulty in overcoming the competency of the ileo-cæcal valve by rectal insufflation of air.

Debierre (*La valvule de Bauhin considérée comme barrière des apothicaires*. *Lyon Médicale*, No. 45, 1885) made numerous experiments on the cadaver to test the permeability of the ileo-cæcal valve to rectal injections of fluids or inflation of air. The results which he obtained were not constant. In some subjects the valve proved only permeable to air; in others, to both air and water, while in some no air or fluids could be forced into the ileum by any degree of force. When the intestine was left *in situ* the valve was found less permeable than when the intestine had been removed from the body. He attributes the different degrees of competency of the valve to variations in the anatomical construction of the valve. If both lips of the valve are equal in length, or if the lower lip is longer the valve was found impermeable. It proved permeable in cases where the lower lip was shorter, contracted and smaller than the upper. In the last instance the advancing volume of fluid or air lifted the upper valve, while in the former structure of the valve the margins of the lips of valve were pressed against each other, perfectly shutting off all communication between the colon and the ileum.

Mr. Lucas ("On Inversion with Inflation in the Cure of Intussusception." *The Lancet*, January 16, 1886) enumerates the following objections against forcible rectal injections of water as a means to reduce an invagination:

1. Owing to its weight it exerts much too strong lateral pressure for the intestine safely to bear, and he has found it easy to rupture the bowel after death by forcing in water.

2. Should reduction have been accomplished the contact of a large quantity of water with the large bowel is apt to increase the tendency to diarrhœa.

He claims, very properly, that air, on the other hand, is a natural occupant of the intestinal canal, and whilst its pressure is of the gentlest its presence excites no unnatural peristaltic action. He administers an anæsthetic to the point of relaxation before the inflation is attempted.

Dawson (*Lancet and Clinic*, Feb. 21, 1885) made a number of experiments on the cadaver and came to the conclusion that when the ileo-cæcal valve is in a normal condition it effectually guards the small intestine against the ingress of fluids from below.

Illoway (*American Journal Medical Sciences*, Vol. 41, p. 168) devised a force-pump which he strongly recommends for the purpose of forcing water beyond the ileo-cæcal valve in case the seat of an intestinal obstruction is located above that point. He reports four cases of intestinal obstruction treated by this method, three of which recovered.

Batthey (*Transactions of the American Medical Association*, 1878) asserts the permeability of the entire alimentary canal by enema, and verifies his statement by the recital of his own clinical experience and experiments upon the cadaver. Ziemssen recommends inflation of the rectum for diagnostic and therapeutic purposes and proceeds as follows: a rectal tube about 6 inches long is carried into the anus and fixed by pressing together the nates, the patient lying on the back. A funnel is then connected with the rectal tube by means of rubber tubing. For complete inflation of the large intestine 3 drams of bicarbonate of soda and $4\frac{1}{2}$ drams of tartaric acid are separately dissolved in water and portions of either solutions alternately added. To prevent sudden overdistension of the bowel it is advised to add the solutions at intervals of several minutes. A very important use of this method is to diagnosticate the position of contractions, strictures, or occlusion of the intestine in cases in which it is desirable to operate, and also as showing the position of peritoneal adhesions. The re-

sult of his observations has led him to believe that, as a rule, the small intestine is completely closed to the entrance of substances from the colon by the ileo-cæcal valve. Under the influence of deep chloroform narcosis, however, this resistance is lessened, and fluids can be thrown into the small intestine.

In my paper read at the last International Medical Congress ("An Experimental Contribution to Intestinal Surgery with Special Reference to the Treatment of Intestinal Obstruction") the following experiments appear which illustrate the difficulty in overcoming the resistance of the ileo-cæcal valve by rectal injections of water:

Experiment 23.—While completely under the influence of ether an incision was made through the linea alba of a cat, sufficiently long to render the ileo-cæcal region readily accessible to light. An incision was made into the ileum just above the valve and by gently retracting the margins of the wound the valve could be distinctly seen. Water was then injected into the rectum and as the cæcum became well distended it could be readily seen that the valve became tense and appeared like a circular curtain preventing effectually the escape even of a drop of fluid into the ileum. The competency of the valve was only overcome by overdistension of the cæcum which mechanically separated its margins, which allowed a fine stream of water to escape into the ileum. The insufficiency of the valve was clearly caused by great distension of the cæcum. That such a degree of distension is attained by no inconsiderable danger was proved by this experiment, as the cat was immediately killed, and on examination of the colon and rectum a number of longitudinal rents of the peritoneal coat was found.

Experiment 24.—In this experiment, a cat was fully narcotised with ether, and while the body was inverted, water was injected per rectum in sufficient quantity, and adequate force by means of an elastic

syringe to ascertain the force required to overcome the resistance offered by the ileo-cæcal valve. Great distension of the cæcum could be clearly mapped out by percussion and palpation before any fluid passed into the ileum. As soon as the obstruction at the valve was overcome, the water rushed through the small intestines, and having traversed the entire alimentary canal issued from the mouth. About a quart of water was forced through in this manner. The animal was killed and the gastro-intestinal canal carefully examined for injuries. Two longitudinal lacerations of the peritoneal surface of the rectum, over an inch in length, were found on opposite sides of the bowel.

Experiment 25.—This experiment was conducted in the same manner as the foregoing, only that the cat was not etherized. More than a quart of water was forced through the entire alimentary canal from anus to mouth. The animal was not killed, and lived for eight days, but suffered during the whole time with symptoms of ileo-colitis. A post-mortem examination was not made in this case, although the symptoms manifested during life leave no doubt that they resulted from injuries inflicted by the injection."

It will thus be seen that in the three cases where fluid was forced beyond the ileo-cæcal valve, in two of them the post-mortem revealed multiple lacerations of the peritoneal coat of the large intestines, while the third animal sickened immediately after the experiment was made, and died, from the effects of the injuries inflicted, eight days later. These experiments combined with clinical experience leave no further doubt that, practically, the ileo-cæcal valve is not permeable to fluids from below, and that for diagnostic and therapeutic uses it is unsafe and unjustifiable to attempt to force fluids beyond the ileo-cæcal valve. We should *a priori* expect that air and gases on account of their less weight and greater elasticity than water, could be forced along the in-

testinal canal with less force, and for that reason alone, if for no other, should be preferred to water in cases where it appears desirable to distend the intestine above the ileo-cæcal valve. The results obtained by experimental research in the past speak in favor of rectal inflation by air or gas in all cases where for diagnostic or therapeutic purposes it becomes necessary to dilate the entire or a portion of the gastro-intestinal canal.

1. Rectal Insufflation of Air.

*Experiment 1.*¹—Dog, weight 75 pounds. The animal was profoundly anæsthetized, and by means of an ordinary elastic syringe air was forced through the rectum until the whole abdomen became distended and tympanitic. The abdominal cavity was opened in the median line, and the whole intestinal canal was found distended. An incision about an inch in length was made about the middle of the small intestines when air escaped, and about one foot of the intestine on either side of the wound collapsed. The remaining portion of the intestines remained unaffected by the incision. The animal was killed, and every part of the entire gastro-intestinal canal was carefully examined for injuries. The ileo-cæcal valve remained intact, and no evidences of rupture of any of the coats of the intestines could be detected.

Experiment 2.—Dog, weight 12 pounds. Under full anæsthesia the gastro-intestinal canal was inflated in the same manner as in the preceding experiment, and the inflation was carried to the same extent. On opening the abdomen in the median line the distended loops of the intestines protruded from the wound and partial eventration was allowed to take place for the purpose of examining the in-

¹These experiments were made at the County Hospital, and my thanks are due to Dr. M. E. Connel, Superintendent of the hospital and his assistants, and Dr. Wm. Mackie of Milwaukee, for valuable assistance.

testines for injuries. The closest inspection failed to detect evidences of partial or complete rupture of any of the tunics. One of the distended coils of the intestine was incised at opposite points on lateral aspect, the incisions being an inch in length. Only a limited segment of the bowel on each side of the wounds collapsed, and although the peristalsis was active more remote portions were emptied very slowly. The wounds were united transversely for the purpose of making an artificial diverticulum. The animal recovered without any untoward symptoms.

Experiment 3.—Dog, weight 13 pounds. Animal profoundly etherized, and air inflated as in former experiments. The distended colon could be clearly mapped out by percussion before a gurgling sound in the region of the ileo-cæcal valve indicated that the air had entered the ileum. After this had occurred the middle of the abdomen became prominent and tympanitic. As soon as the resistance offered by the ileo-cæcal valve had been overcome it required less force in distending the remaining portion of the gastro-intestinal canal. The inflation was carried to the extent of distending the stomach, an event which was easily recognized by a considerable prominence in the epigastric region which was tympanitic on percussion. At this time an elastic tube was inserted into the stomach, and its free end immersed under water. Bubbles of air escaped freely, and the abdominal distension was materially diminished. As the inflation was continued the air would escape through the stomach-tube, showing that a moving current of air existed between the rectal tube and the stomach tube. The abdominal distension which remained after the experiment had completely disappeared after eighteen hours, and the animal never manifested pain or any other symptoms of disease.

Experiment 4.—Dog, weight 15 pounds. In this experiment inflation was practiced without anæs-

thesia. The rigidity of the abdominal muscles greatly interfered with the distension of the colon to a requisite degree for overcoming the competency of the ileo-cæcal valve. The passage of air from the cæcum into the ileum through the ileo-cæcal valve was announced by an audible gurgling sound which was repeated at intervals, as the cæcum, after partial collapse, again was distended by renewing the inflation. The insufflation was continued until the stomach became distended by air, which caused vomiting and copious eructations of air. The dog remained in perfect health after the inflation.

These experiments prove the feasibility of forcing air through the entire alimentary canal from below upwards. In not a single experiment could any structural changes be found in the walls of the intestine, and all animals not killed immediately after the experiment recovered. The results of these experiments contrast strongly with those where the same objects were in view by rectal injections with water. In the latter experiments the force requisite to overcome the ileo-cæcal valve invariably produced lacerations of the peritoneal coat of the bowel, which in themselves would constitute a grave source of danger. It now became necessary for me to prove that the ileo-cæcal region in man in so far resembled that in the dog that the ileo-cæcal valve could be rendered more readily incompetent by inflation of air than by injections of fluids. The following two experiments were made for this purpose:

Experiment 5.—A young man, 25 years of age, a patient in the Milwaukee Hospital under treatment for a tumor in the epigastric region, was subjected to the experiment. He was placed flat on the back. On percussion the whole umbilical region was found flat and the abdominal wall retracted. No anæsthesia. With an ordinary elastic syringe air was injected slowly into the rectum. As inflation progressed the outlines of the entire colon could be

clearly seen and accurately mapped out by percussion. The cæcal region especially became very prominent. The inflation was continued very slowly, and as soon as the air passed through the ileo-cæcal valve the hypogastric and umbilical regions began to rise and resonance replaced the former dulness on percussion. The arrival of air in the stomach was indicated by distension of the epigastric region, disappearance of the contour of the tumor and resonance on percussion. During the whole process of inflation the patient only complained of a slight pain in the splenic flexure of the colon, and a sensation of fullness in the abdomen. As soon as it became apparent that the stomach was distended by air a stomach-tube was introduced and its free end was placed under water. As the inflation was continued bubbles of air continued to escape. On assuming the erect position the patient complained of colicky pains in the umbilical region which undoubtedly were caused by an exaggerated peristalsis. The pain, however, soon disappeared, and on the following day he was as well as usual.

Experiment 6.—Adult male, suffering from neurasthenia. Experiment and result the same as in No. 5, only that in this case the pain due to distension of the colon was referred to the ileo-cæcal region, and the colicky pain in the umbilical region persisted for a longer time. The air was again forced from anus to mouth without causing any injury whatever and only moderate degree of pain for a short time.

The foregoing experiments demonstrate conclusively that in the human subject by a moderate degree of force, short of producing any injury of the tunics of the intestines, air can be forced along the entire alimentary tract, and that this procedure can be resorted to with perfect safety for diagnostic and therapeutic purposes in all cases where the tissues of the intestinal wall have not suffered too much loss of resistance from antecedent pathological changes.

2.—Inflation of Alimentary Canal through Stomach Tube.

We should naturally expect that the alimentary canal could be inflated with more ease and with a less degree of force by following the normal peristaltic wave. That this is not the case will be seen from the following experiment:

Experiment 7.—Dog, weight 40 lbs. (18 kilograms). After complete anaesthesia was effected a flexible rubber tube was introduced into the stomach and the free end of the tube connected with a four-gallon rubber balloon, containing hydrogen gas, by means of a rubber tube. Between the gas reservoir and the stomach-tube a manometer was interposed, registering accurately the force used in making the inflation. The inflation was made by compressing the rubber bag. A tube was introduced into the rectum to facilitate the escape of gas that might reach this portion of the intestinal tract. Under a pressure of one pound and a half the stomach dilated rapidly, and later the entire abdomen became distended and resonant on percussion, but no gas escaped per rectum. When the pressure was increased to two pounds (1 kilogram) no further distension of the abdomen took place, as the gas escaped along the side of the stomach tube. At this time respiration became greatly embarrassed, but was relieved on allowing gas to escape through the stomach-tube. On compressing the abdomen firmly the distension disappeared almost completely, at the same time a large quantity of gas continued to escape through the stomach tube. Inflation was renewed, and under a pressure of one pound and a half, the abdomen again became uniformly distended. When the pressure was increased to two pounds (1 kilogram) the dog suddenly died, and all efforts at resuscitation failed. On opening the abdomen the stomach was found enormously distended, reaching three inches

below the umbilicus, occupying almost the entire abdominal cavity. The upper half of the small intestines was distended; numerous points of sharp flexions were found among the different distended coils. The distended stomach had evidently encroached so much upon the abdominal space as to render the greater part of the intestinal canal impermeable by pressure.

Experiment 8.—Dog, weight 15 lbs. After the animal was placed fully under the influence of ether the abdomen was opened and the cæcum and lower portion of ileum drawn forward into the wound, and a large needle of an aspirator inserted into the ileum just above the ileo-cæcal valve. Through a rubber tube hydrogen gas was forced into the stomach. Under one pound (5 hectograms) of pressure the stomach and upper portion of the intestines dilated readily. When the force was increased the gas returned through the œsophagus along the sides of the stomach-tube.

Experiment 9.—Dog, medium size. This animal was killed to ascertain the results of an experiment made for another purpose. Rubber balloon containing hydrogen gas and manometer were used for making the inflation. The tube through which the inflation was made was tied in the œsophagus. The abdomen was distended enormously, and on increasing the pressure to three and three-fourths pounds ($1\frac{1}{2}$ kilograms), still no gas escaped through the rectal tube. The abdomen was then opened, when the stomach was found so enormously distended that it filled almost the entire abdominal cavity. About one-fourth of the length of the small intestines was found distended, and among the distended loops numerous acute flexions could be seen. After the abdomen was opened, under long and continuous distension, the peritoneal covering of the stomach gave way, when the manometer registered only one pound and a half of pressure.

Experiment 10.—Dog, weight 18 lbs. (8 kilograms). Immediately after death the oesophagus was isolated and the tube of the hydrogen gas inflator securely tied in, and a glass tube was inserted into the rectum. Under a pressure of two and three-fourths pounds (1.2 kilograms) registered by the manometer the gas first dilated the stomach and then passed along the intestines until it escaped in a steady stream through the rectal tube, where it was ignited. On opening the abdomen the stomach was found greatly distended, while the distension of the intestines was a great deal less marked. None of the tunics of the stomach or intestines were injured.

Experiment 11.—Dog, weight 20 lbs. (9 kilograms). Animal etherized and a flexible tube connected with the gas inflator introduced into the stomach and a glass tube into the rectum. On inflation the stomach became gradually distended, and when the pressure had reached one pound and a half (.6 kilogram) the dog vomited and a good deal of gas escaped at the same time. Inflation was again commenced and was followed by uniform distension and tympanitis over the entire abdomen, when the pressure reached two pounds and a half (1 kilogram) the gas escaped from the rectum, and when ignited burned with a steady blue flame. The experiment was followed by no unfavorable symptoms.

Experiment 12.—Dog, weight 12 lbs. (5½ kilograms). Under the influence of ether inflation with hydrogen gas in the same manner as in last experiment. As soon as the stomach became well distended, and the manometer registered one pound and a half of pressure, vomiting occurred, attended by a free escape of gas, which was followed by collapse of the distended epigastric region. When inflation was again resumed, it was noted that any increase of pressure over one pound (.45 kilogram) was followed by regurgitation of gas, and on this account it was found impossible to inflate the lower

portion of the intestinal tract. No unfavorable symptoms followed the experiment.

Experiment 13.—Dog, weight 28 lbs. ($12\frac{1}{2}$ kilograms). Under the influence of ether inflation of hydrogen gas through stomach tube. As soon as the pressure was increased to more than 1 lb. (.45 kilogram) the gas escaped along the sides of the tube through the œsophagus, consequently only the upper portion of the abdomen could be distended, and the inflation evidently did not extend much beyond the stomach. The experiment was repeated several times with the same result. The animal remained perfectly well after the experiment.

Experiment 14.—Dog, weight 12 lbs. (5 kilograms). Inflation of stomach by hydrogen gas under full anæsthesia. The effect of the inflation was the same as in the last experiment, only the stomach and upper portion of the small intestines could be distended and further inflation was impossible, as the gas escaped from the stomach as soon as the pressure exceeded 1 lb. (.45 kilogram). A large needle of an aspirator was pushed through the linea alba into the stomach, and the gas which escaped through it on being lighted burned with the characteristic blue flame. After the needle was withdrawn the inflation was continued to ascertain if the puncture in the stomach would allow the escape of gas into the peritoneal cavity. The inflation was continued until the entire abdomen was distended by the gas. That the distension and tympanites was due to the presence of gas in the peritoneal cavity became evident, as it remained after the stomach had been emptied of its gas, and on percussion it was ascertained that the entire liver dulness had disappeared. The dog recovered without symptoms of peritonitis or any other ill-effects from the experiment.

These experiments demonstrate conclusively that it is more difficult to inflate the alimentary canal from above downwards than from below upwards, as in

the living animal I succeeded only in one instance in forcing hydrogen gas from mouth to anus, while in others a degree of force sufficient to rupture the peritoneal coat of the stomach only effected distension of the stomach and upper portion of intestinal canal. It is evident that great distension of the stomach constitutes an important factor in causing or aggravating intestinal obstruction, as it effects compression which causes impermeability of the intestines, or aggravates conditions arising from an antecedent partial permeability by producing sharp flexions among the distended coils of the intestines. For diagnostic and surgical purposes the stomach can be readily inflated almost to any extent through a stomach tube, and when it becomes necessary to ascertain the presence of a visceral wound or perforation of this organ, this method of inflation may be resorted to with advantage.

3. *Experiments to Determine the Degree of Force which is Necessary to Overcome the Resistance offered by the Ileo-cæcal Valve.*

Accurate experiments to determine the force required to render the ileo-cæcal valve incompetent by insufflation of air or gas have so far not been made, and as it is exceedingly important to obtain some accurate information on this subject, the following experiments were made. In all experiments air or hydrogen gas was used. The inflation was made with a rubber balloon. The pressure was estimated either with a mercury gauge, or with a manometer used by gas-fitters and plumbers. The manometer or mercury gauge was connected by means of rubber tubing with the rectal tube on one side and the rubber balloon on the other. The rubber balloon in which the hydrogen gas was collected held 4 gallons, and numerous experiments showed that when the gas was forced through the opening of a stopcock, the lumen of which was about the size of a knitting needle, a

compression equal to 200 lbs. (90 kilograms) would never register more than 3 lbs. (1.3 kilograms) of pressure.

In the living subject the escape of air or gas from the rectum was prevented by an assistant pressing the margins of the anus firmly against the rectal tube.

Experiment 15.—Dog, weight 35 lbs. (16 kilograms). Immediately after death the lower portion of the rectum was isolated and the rectal tube inserted and fixed in its place by tying a string firmly around the rectum. The abdomen was opened and the intestines left *in situ*. The ileum was cut transversely 6 inches above the ileo-cæcal valve and a glass tube inserted into the distal end, which was also tied in. Hydrogen gas was inflated from a rubber balloon. Under a pressure of $\frac{3}{4}$ -lb. (.3 kilogram) the cæcum was dilated, and a moment later the gas escaped from the glass tube and was ignited; the flame remained steady under a pressure of from $\frac{1}{2}$ - to $\frac{3}{4}$ -lb. (.2 to .3 kilogram).

Experiment 16.—Dog, weight 20 lbs. (9 kilograms). Same as in the preceding experiment, only that the resistance of the ileo-cæcal valve was overcome under a pressure of $\frac{1}{2}$ -lb. (.2 kilogram). The distension of colon and cæcum was moderate, and signs of injury to its tunics could not be found in either experiment.

Experiment 17.—Dog, weight 23 lbs. (10 kilograms). In this experiment the abdomen was opened immediately after death, and a large hypodermic needle inserted into the ileum a short distance above the ileo-cæcal valve before the inflation of hydrogen gas was made. A pressure of $\frac{3}{4}$ lb. (.3 kilogram) was sufficient to force the gas through the ileo-cæcal valve and through the needle; the valve remained open under a steady pressure of $\frac{1}{2}$ -lb. (.2 kilogram). Having determined that air and gas can be forced beyond the ileo-cæcal valve in dogs under very low pressure, varying from $\frac{1}{2}$ - to $\frac{3}{4}$ -lb., I proceeded to

test the degree of resistance of the ileo-cæcal valve in the human subject.

Experiment 18.—Strong, healthy young man. The subject was placed flat upon his back and hydrogen gas was inflated from a rubber balloon. At first the gas was forced in very slowly under a pressure of $1\frac{1}{2}$ lb. (.6 kilogram), which distended the colon visibly as far as the cæcum. As the distension appeared to remain the same the pressure was increased to 2 lbs. (.9 kilogram), when suddenly the indicator of the manometer receded to 1 lb. (.4 kilogram), and the umbilical region became prominent and resonant, showing conclusively that the ileo-cæcal valve had been passed and the small intestines were filling rapidly with gas. As soon as the whole abdomen had become distended and tympanitic the manometer again registered $1\frac{1}{2}$ lb. (.6 kilogram) of pressure, and remained at this figure for some time after further inflation was discontinued by turning the stopcock.

Experiment 19.—Young man, in good health. Experiment conducted in the same manner as in the foregoing. After the colon and cæcum had been well dilated the manometer registered $2\frac{1}{4}$ lbs. (.4 kilogram), and the umbilical region became prominent and resonant. As the inflation advanced the average pressure was $1\frac{3}{4}$ lb. (.8 kilogram), and twice it was increased to $2\frac{1}{2}$ lbs. (1.4 kilogram), when the patient complained of pain in the umbilical region. As soon as the stopcock was turned the pressure sank to $\frac{3}{4}$ -lb. (.3 kilogram). These two experiments prove that in a normal condition the ileo-cæcal valve in a healthy adult person is overcome by rectal inflation under a pressure of $1\frac{1}{2}$ to $2\frac{1}{4}$ lbs. (.6 to 1.2 kilogram). This amount of pressure is not sufficient to injure the tunics of a healthy intestine, and in both instances the subjects of the experiments complained but little of the immediate or remote effects of the experiment. As the result of numerous observations, I can state that when the inflation is made slowly and

continuously there is less danger of injuring the intestines than when the inflation is made rapidly, or with interruptions. Slow and gradual distension of the cæcum is best adapted to overcome the competency of the ileo cæcal valve, by effecting diastasis of the margins of the valve. A rubber balloon holding from 2 to 4 gallons (10 to 20 litres) recommends itself as the most efficient and safest instrument for making rectal insufflation for therapeutic or diagnostic purposes.

The following experiments were made to determine:

4. *The Amount of Pressure Necessary to Force Hydrogen Gas through the Entire Alimentary Canal by Rectal Inflation.*

Experiment 20.—Dog, weight 35 pounds (16 kilograms). Immediately after death rectal inflation of hydrogen gas was made, and a pressure of one pound (.4 kilograms) sufficed to distend the entire abdominal cavity, and when a tube was introduced into the stomach and a burning taper applied to its end a blue flame at once appeared and continued as long as the inflation was kept up under the same pressure.

Experiment 21.—Dog, weight 12 pounds (5 kilograms). Under ether narcosis rectal inflation of hydrogen gas from rubber balloon. The ileo-cæcal valve offered very little resistance, and as soon as the manometer registered one pound and a half (.6 kilogram) of pressure the gas escaped through the stomach tube which had been introduced previously, and on applying a lighted taper it burned with a continuous flame as long as the inflation was continued.

Experiment 22.—Dog, weight 20 pounds (9 kilograms). Experiment and result same as in last; the pressure never exceeded one pound and a half (.6 kilogram).

Experiment 23.—Dog, weight 19 pounds (9 kilo-

grams). In this experiment no anæsthetic was used, and in consequence the pressure had to be increased to three pounds (1.3 kilograms) before the gas escaped through the stomach tube. On account of the violent contractions of the abdominal muscles the escape of gas was intermittent, the flame being frequently extinguished by an absence of the gas.

Experiment 24.—Dog, weight 21 pounds (10 kilograms). The animal being completely under the influence of ether the abdomen was opened in the median line, and the ileo-cæcal region made accessible to sight. Hydrogen gas was inflated per rectum, and under a pressure of three-quarters of a pound (.3 kilogram) readily passed the ileo-cæcal valve, and under one pound of pressure it ascended the intestinal canal, and in a few seconds reached the stomach. A tube was introduced into the stomach, and as the gas escaped it was ignited and burned with a steady flame.

Experiment 25.—Dog, weight 18 pounds (8 kilograms). Rectal insufflation of hydrogen gas, the dog being fully under the influence of an anæsthetic. The colon and cæcum were only slightly distended when the gas under one-quarter of a pound (.1 kilogram) of pressure passed the ileo-cæcal valve. Under one pound (.4 kilogram) of pressure the abdomen became uniformly distended and tympanitic, and when a tube was introduced into the stomach the escaping gas was ignited and burned with a steady flame as long as the pressure was continued.

Experiment 26.—Dog, weight 20 pounds (9 kilograms). Animal etherized, and when completely relaxed hydrogen gas was inflated per rectum, and passed the ileo-cæcal valve under a pressure of half a pound (.2 kilograms). The stomach became distended under a pressure of one pound and a half (.6 kilogram), and on the introduction of a tube the escaping gas was ignited and burned with a continuous flame as long as the manometer registered half a

pound (.2 kilogram) of pressure. In all animals where the insufflation was not complicated by abdominal section no unpleasant symptoms followed the experiments. All of the animals recovered as rapidly as after an ordinary ether narcosis. In all of the experiments the pressure fell rapidly after the ileo-cæcal valve had been opened, but the pressure had again to be increased before the gas reached the stomach. It usually required one-half to one pound more pressure to force gas through the entire alimentary canal than when it was forced only through the ileo-cæcal valve. Whenever it becomes desirable to conduct the hydrogen gas a considerable distance along the intestines, or through the entire alimentary canal, it is exceedingly important to proceed slowly with the inflation, as under slow distension on half a pound (.2 kilogram) of pressure will accomplish in time a greater degree of distension than four times this amount of pressure if the force is applied quickly, and only for a short time, and is attended by much less risk of injury to the coats of the intestines. I am quite convinced that in the dog rectal insufflation of hydrogen gas made under a pressure of one-quarter of a pound, if made very slowly, the abdominal walls being completely relaxed by an anæsthetic, will not only overcome the resistance offered by the ileo-cæcal valve, but will prove sufficient to force the gas through the whole length of the alimentary canal. I have now sufficiently demonstrated the permeability of the ileo-cæcal valve and the entire alimentary canal in animals and man to rectal insufflation of air and gas, and I shall now endeavor to establish the safety of this procedure as a diagnostic and therapeutic measure by showing:

II. THE RESISTANCE OF DIFFERENT PORTIONS OF THE GASTRO-INTESTINAL CANAL TO DIASTALTIC FORCE.

a. Stomach.

Experiment 27.—Large, healthy, adult dog. Experiment made immediately after death. Stomach *in situ*. Œsophagus tied and distension made with a force pump from pyloric orifice, the organ being rapidly dilated with air. When the manometer registered eight and one-half pounds (3.8 kilograms) of pressure the stomach was distended at least eight times its normal size, when a rent in the peritoneal covering an inch and a half in length parallel to, and near the omental attachment occurred.

Experiment 28.—Middle aged man, died of sepsis. The whole gastro-intestinal canal showed marked evidences of septic gastro-entero-colitis, the mucous membrane being softened, very vascular, and dotted with numerous hæmorrhagic infarcts. Organ *in situ* inflated with air in the same manner as in last experiment. Longitudinal rupture of peritoneal coat along anterior surface under two and one-half pounds of pressure (1.1 kilogram), and when it was increased to three pounds (1.3 kilograms) the whole thickness of the wall at the lesser curvature ruptured.

b. Small Intestines.

Experiment 29.—Subject same as in experiment 28. Lower portion of ileum under five pounds (2.2 kilograms) of pressure became emphysematous along mesenteric attachment, and ruptured completely as soon as the manometer registered five and three-fourths (2.3 kilograms) pounds of pressure.

Experiment 30.—Dog, weight 20 lbs. (9 kilograms). Immediately after death the lower part of the ileum, with mesenteric attachment intact, was gradually distended and remained intact until a pressure of ten pounds (2.5 kilograms) was reached, when air es-

caped between the two serous layers of the mesentery, showing that minute ruptures at numerous points had taken place. When the distension had reached its maximum the segment of bowel inflated was elongated twice its normal length.

Experiment 31.—Upper portion of ileum of same animal when distended to its utmost gave way under a pressure of eight pounds (3.6 kilograms), the peritoneal coat on convex side rupturing to the extent of 2 inches (51 mm.) parallel to the axis of the bowel.

Experiment 32.—The middle portion of the small intestines, when subject to a pressure of eight pounds (3.6 kilograms), sustained a longitudinal rupture of the peritoneum on convex surface, and remaining tunics gave way when the pressure was increased to nine pounds (4 kilograms).

c. Colon.

Experiment 33.—Subject same as experiments 28 and 29. Experiment was made twenty-four hours after death. Colon and cæcum apparently very much softened and mucous membrane in a state of inflammation. One foot (3 d. m.) of the transverse colon isolated and gradually distended when the peritoneal coat along the border of one of the longitudinal bands ruptured under a pressure of two pounds and a half (1 kilogram). The peritoneal laceration became very extensive before the remaining tunics ruptured under a pressure of four pounds (1.8 kilograms).

Experiment 34.—Dog, weight 18 lbs. (8 kilograms). Immediately after death the ileum was tied just above the cæcum and the inflation made per rectum. Air was pumped in gradually with a force-pump and when the pressure reached ten pounds and a half (4.7 kilograms) air escaped between the peritoneal layers of the meso-colon; at this stage the longitudinal distension of the bowel exceeded twice its normal length.

Experiment 35.—Dog, weight 23 lbs. (10 kilograms).

Experiment the same as the preceding. Air was pumped in rapidly until the mercury gauge registered ten and a half pounds (4.7 kilograms) of pressure, when the sigmoid flexure on its free surface gave way with a loud report, the rent being about one inch and a half (38 mm.) in length.

Experiment 36.—Dog, weight 18 lbs. (7 kilograms). Entire colon distended by rectal inflation of air, the ileum being tied just above the ileo-cæcal valve. Under a pressure of six pounds (2.7 kilograms) the peritoneum ruptured in a longitudinal direction, opposite the meso-colon, and the remaining tunics gave way a little later under the same pressure.

These experiments are of the greatest importance in showing that the pressure which was found necessary to apply in rupturing a healthy intestine was greatly in excess of that which is required to force air through the ileo-cæcal valve, or even the whole length of the alimentary canal. It only requires from one-quarter of a pound to a pound and a half (.1 to .7 kilograms) of pressure to force air through the ileo-cæcal valve, and from half a pound to two pounds and a half (.2 to .7 kilograms) to force it from anus to mouth, while even the weakest portion of the gastro-intestinal canal effectually resisted a distending force of from eight to ten pounds (3.6 to 4.5 kilograms). The experiments on the human cadaver, where the resisting power of the gastro-intestinal canal to diastatic force was greatly reduced by antemortem pathological changes, show that under such circumstances it would have been safe to resort to inflation, as the pressure required to rupture the colon or small intestines exceeded that which has been found adequate to force air or gas beyond the ileo-cæcal valve, or even the entire length of the alimentary canal. When an intestine is distended to its utmost capacity slowly by inflation of air or gas, and the pressure is maintained uninterruptedly, rupture occurs at one of two points, either a longitudinal

laceration of the peritoneal coat takes place on the convex surface of the bowel opposite the mesenteric attachment, or minute ruptures on the mesenteric side give rise to extravasation of air or gas between the two serous layers of the mesentery, in either case, if the pressure is increased, complete rupture takes place at the point where the laceration first commenced.

III. DISTENSION OF GASTRO-INTESTINAL CANAL BY RECTAL INSUFFLATION OF HYDROGEN GAS.

This part of the paper contains an account of the experiments which were made preliminary to the practical application of the hydrogen gas test as a diagnostic measure in penetrating wounds of the abdomen, and furnish only so many more demonstrations of the permeability of the ileo-cæcal valve and the entire alimentary canal to rectal inflation of hydrogen gas.

Experiment 37.—Dog, weight 15 lbs. (6 kilograms). Under ether anæsthesia hydrogen gas from rubber balloon was slowly forced into the rectum until the entire anterior abdominal wall had become uniformly distended and tympanitic, when the distended stomach was punctured with a large needle of an aspirator and gas escaped in a steady stream, and when ignited burned with a continuous flame. After a considerable portion of gas had been evacuated in this manner the upper abdominal region receded and the flame was extinguished. The animal recovered without any untoward symptoms.

Experiment 38.—Dog, weight 17 lbs. (7 kilograms). Without anæsthesia hydrogen gas was inflated per rectum until it escaped through a tube which had been introduced into the stomach. As it escaped from the stomach tube it was ignited and burned with a large blue flame. The abdominal muscles were so rigid that distension was never well marked, and the inflation required a good deal more force than in

animals where muscular rigidity has been overcome by an anæsthetic. The dog remained perfectly well after the experiment and in a few hours the remaining tympanites had disappeared.

Experiment 39.—Dog, (weight 35 lbs. (15 kilograms). No anæsthetic used. On account of rigidity of abdominal muscles it required persistent efforts to force hydrogen gas from rubber balloon per rectum through the whole alimentary canal. As soon as the stomach had become distended by the gas the animal vomited, at the same time gas escaped by repeated eructations. The animal manifested no signs of suffering after the experiment.

Experiment 40.—Dog, weight 27 lbs. (12 kilograms). Under anæsthesia hydrogen gas was inflated per rectum until it escaped through tube which had been introduced into the stomach; a lighted taper was applied to the free end of the tube and the gas ignited and burned with the characteristic blue flame.

Experiment 41.—Large Newfoundland dog. Under anæsthesia a duodenostomy was made, and hydrogen gas injected per rectum and ignited as it escaped from a rubber tube which had been inserted into the distal portion of the bowel through the fistula.

Experiment 42.—Adult male; abdominal organs healthy; no anæsthesia. Inflation of hydrogen gas per rectum. The gas was stored in a four-gallon (9 litres) rubber balloon and was forced into the rectum by compression. As the distension progressed the colon could be distinctly mapped out from sigmoid flexure to cæcum by inspection and percussion. As soon as the cæcum had become visibly prominent a stethoscope was applied over the ileo-cæcal region, and as the valve became incompetent by overdistension of cæcum a distinct gurgling sound could be heard as the gas entered the ileum. Whenever inflation was arrested the gurgling sound disappeared

and was heard again whenever the ileo-cæcal valve was opened by renewed inflation.

Distension of the small intestines was attended by resonance and prominence of umbilical and hypogastric regions. The incompetency of the ileo-cæcal valve was invariably announced by a reduction in the pressure. The patient complained of a sensation of distension in the umbilical region and intermittent colicky pains which, however, disappeared completely after a few hours. The pain appeared to be less severe than after similar experiments with inflation of air.

Experiment 43.—Young man in comparatively good health. Inflation same as in preceding experiment. Auscultation over ileo-cæcal valve revealed the same sounds as the gas escaped from the colon into the ileum. The sound seemed to vary somewhat according to the size of the opening in the valve and the force used in making the inflation, and always disappeared as the valve closed after suspension of inflation. The colicky pains subsided as the small intestines emptied themselves of their new contents. The assistant who compressed the rubber balloon was always able to announce the beginning of the incompetency of the ileo-cæcal valve by experiencing a sudden diminution in the pressure.

Experiment 44.—Adult male, suffering from gastric catarrh. Hydrogen gas inflation per rectum to extent of causing great distension of abdomen which caused the hepatic dulness to ascend at least two inches. Auscultatory signs the same. Sharp colicky pains in the umbilical region were relieved by a free escape of gas through rectum.

Experiment 45.—Hysterical female. Abdomen flat and dull on percussion from umbilicus to pubis; no resonance over sigmoid flexure. Rectal inflation with hydrogen gas. Compression of rubber balloon corresponding to only one-fourth pound (.1 kilogram) of pressure readily dilated the whole colon, its course

being indicated by a distinct prominence and tympanitic resonance from sigmoid flexure to cæcum. Under the same pressure the gas escaped with little or no resistance through the ileo-cæcal valve from the colon into the ileum, the occurrence being attended by the characteristic auscultatory sounds and followed by distension and resonance of space from umbilicus to pubis. Amount of gas inflated about four litres. The patient complained of some pain in the region of the splenic flexure of the colon during the distension of the colon, and later of slight intermittent pain in the region of the umbilicus.

Experiment 46.—Middle-aged woman, suffering from retroversion of the uterus. Abdomen flaccid and dull on percussion in the median line from umbilicus to pubis. Rectum distended with hardened fæces. Hydrogen gas inflated in the usual manner. The mercury gauge registered two and a half pounds (1 kilogram) of pressure before the gas reached the sigmoid flexure, after this it fell to one pound (.4 kilogram) and the inflation progressed without any further resistance. As soon as the gas passed through the ileo-cæcal valve the pressure fell to three-quarters of a pound (.3 kilogram) and remained so during the inflation of the small intestines, slight variations marking the opening and closing of the ileo-cæcal valve. As the umbilical and hypogastric regions became prominent and tympanitic the patient complained of a griping pain. About eight litres of gas were injected. A few hours after the experiment all symptoms had disappeared.

Experiment 47.—Female recently operated on for laceration of perineum. Rectum empty. Abdomen flaccid; umbilical, hypogastric, and right iliac regions dull on percussion. The inflation was made very slowly and the pressure never exceeded 1 lb. (.4 kilogram). As the large intestine became distended the transverse colon came plainly into view. On auscultation over the ileo-cæcal valve the escape of gas into

the ileum was marked by a blowing sound, which in pitch was increased or diminished by the degree of pressure. As the lower portion of the small intestines became distended the lower part of the abdomen became prominent and tympanitic, and the patient complained of colicky pains. About 3 litres of gas were inflated. In half an hour the patient appeared as well as before inflation.

Experiment 48.—Middle-aged physician suffering from typhlitis. This was the second attack, and the acute symptoms had subsided. Over the cæcum a circumscribed area of dulness and tenderness. On palpation it appeared as though the swelling were adherent to the anterior abdominal wall. The area of dulness was outlined externally by pencil marks before inflation was commenced. As the colon became distended under a pressure of $\frac{1}{4}$ -lb. (.1 kilogram), the circumscribed, indurated region became more prominent, imparting to the palpating fingers the feeling of hardness, but on percussion it was resonant, showing conclusively that the inflamed and indurated wall of the cæcum had been lifted forwards by the pressure of the gas. Under the same pressure the gas escaped in a continuous stream into the ileum, its passage through the ileo-cæcal valve being attended by a well-marked blowing, gurgling sound. The patient felt the entrance of gas into the ileum distinctly and complained soon after of a slight colicky pain in the umbilical region. The space between umbilicus and pubis, which before inflation was completely dull on percussion, now became more prominent and tympanitic. Only 2 litres of gas were used in this experiment.

Experiment 49.—Young physician in perfect health. Region between umbilicus and pubis perfectly dull on percussion, also left iliac fossa. Inflation of 4 litres of hydrogen gas under $\frac{1}{3}$ -lb. (.15 kilogram) pressure. The outlines of the distended colon could be clearly seen and marked out by per-

cussion before the gas escaped into the small intestines. The passage of gas through the ileo-cæcal valve was again attended by a well-marked gurgling sound, after which the entire abdomen became prominent and tympanitic. The patient felt a sensation of distension during the inflation of the colon, and as the small intestines became distended complained of griping pains, gas escaped freely by eructations and per rectum, which soon relieved the colicky pains in the umbilical region.

Experiment 50.—Medical student in robust health. Region from umbilicus to pubis flat on percussion, while the course of the entire colon was tympanitic. Rectal inflation with hydrogen gas. As the resistance of the ileo-cæcal valve was overcome the mercury gauge registered $\frac{1}{2}$ -lb. (.2 kilogram) of pressure. The passage of gas through the ileo-cæcal valve was attended by a gurgling sound which was heard at some distance by a number of persons present in the room. Later a continuous blowing (almost amphoric) sound could be heard over the ileo-cæcal valve. The subject of the experiment was conscious of the passage of gas from colon into ileum, and soon after complained of a colicky pain which he referred to the umbilical region. The whole abdomen became uniformly distended and tympanitic on percussion, and the distress caused by the great distension was only relieved by a free escape of gas by eructations and through the rectum. Four litres of gas were used in this experiment.

Experiment 51.—Young physician in good health. Rectal inflation of 4 litres of hydrogen gas under a pressure of only $\frac{1}{3}$ -lb. (.15 kilogram). Distension of colon well-marked previous to escape of gas through the ileo-cæcal valve. As soon as the gas entered the ileum the middle and lower portion of the abdomen became distended and tympanitic. The inflation was continued until the stomach became distended and gas escaped by eructation. The

subject of the experiment complained of quite severe colicky pains as long as the small intestines remained distended by gas.

Experiment 52.—The writer of this paper, being desirous of experiencing himself the sensations which would be caused by inflation of hydrogen gas, submitted himself to experimentation under a pressure of $\frac{1}{2}$ -lb. (.2 kilogram). Nearly 6 litres of gas were inflated *per rectum*. The distension of the colon caused simply a feeling of distension along its course, but as soon as the gas escaped into the ileum colicky pains were experienced, which increased as insufflation advanced, and only ceased after all the gas had escaped, which was the case only after an hour and a half. When the intestines and the stomach had become fully distended the feeling of distension was distressing, and was attended by a sensation of faintness which caused a profuse clammy perspiration. A great deal of the gas escaped by eructation, which was followed by great relief. The colicky pains attending inflation of the small intestines by air or gas are evidently caused by increased peristaltic action of the bowels in their attempt to expel their contents, as it always assumed an intermittent type and subsided promptly after the escape of the gas.

In none of these experiments did the pressure exceed 1 lb. (.4 kilogram) in overcoming the resistance offered by the ileo-cæcal valve, and often a steady, long-continued pressure of $\frac{1}{4}$ - or $\frac{1}{3}$ -lb. (.1 to .15 kilogram) sufficed. Every time the ileo-cæcal valve was rendered incompetent by distension of the cæcum the pressure was promptly diminished owing to the escape of gas from the colon into the ileum. In the experiment where the inflation was made in a case of typhlitis the ileo-cæcal valve offered no resistance, and the gas escaped freely into the ileum; the valve in all probability had been rendered partially or completely incompetent during the course of the local inflammation, or the indurated, thickened

walls of the cæcum, when distended during the inflation, were better adapted in effecting incompetency of the valve. These experiments also furnish strong proof of the fact that inflation, to be safe and effective, should be done very slowly under a low, steady pressure, continued only for a short time, and is attended by no risks whatever of rupturing a healthy intestine and, when cautiously practiced, can be resorted to even in cases where the resisting power of the intestinal wall has been diminished by antecedent pathological processes.

As I was searching for an innocuous, non-irritating gas which, when inflated into the gastro-intestinal canal, would escape into the peritoneal cavity in case a wound or perforation existed, and had decided on trying hydrogen gas, it became necessary to study experimentally the effect of this gas on the different tissues of the living body. The numerous inflation experiments on man and dogs have demonstrated the safety of pure hydrogen gas when employed in this manner, as not in a single instance were any immediate or remote toxic symptoms observed which could be referred to absorption of the gas; hence we have the assurance that the inflation of a large quantity of hydrogen gas is unattended by any risk whatever as far as intoxication is concerned. The following experiments also show the innocuity and non-irritating qualities of hydrogen gas when brought in contact with the most susceptible tissues to inflammatory reaction in the living body; at the same time they also show that hydrogen gas is removed by absorption in a comparatively short time when injected into serous cavities or into the subcutaneous connective tissue.

IV.—HYDROGEN GAS IS INNOCUOUS AND NON-IRRITATING WHEN BROUGHT IN CONTACT WITH LIVING TISSUES AND IS PROMPTLY REMOVED BY ABSORPTION.

a.—Peritoneal Cavity.

Experiment 53.—Dog, weight 45 lbs. A circumscribed spot to the right of the linea alba was shaved and thoroughly disinfected and through this space a well disinfected medium sized trocar was plunged into the peritoneal cavity. To the cannula of the trocar the rubber tube of the inflation balloon charged with hydrogen gas was attached and the whole peritoneal cavity filled with gas by compressing the balloon. About four litres of gas were injected. No gas escaped upon the withdrawal of the cannula and the puncture was sealed with cotton and iodoform collodium. The animal appeared to suffer but little pain, and the next day the tympanitis had disappeared and the dog was as frisky and lively as before the inflation. Two days after the experiment was made the dog was killed and the peritoneal cavity carefully examined. Not a trace of the gas remained and the peritoneum throughout presented a normal appearance.

b.—Pleural Cavity.

Experiment 54.—Dog, weight 25 lbs. After thorough disinfection an aseptic hollow needle was inserted between the seventh and eighth ribs in the axillary line into the left pleural cavity and hydrogen gas from rubber balloon forced through it until the pleural cavity was thoroughly distended. On making a physical examination of the chest at this time the apex of the heart was found to the right of the sternum; vesicular breathing on left side absent, and on percussion of this side abnormal resonance. The respirations became superficial and greatly increased in frequency. On withdrawing the needle no gas escaped externally, but a circumscribed sub-

cutaneous emphysema which appeared showed that some of the gas escaped through the puncture in the pleura into the subcutaneous connective tissue. Twenty-four hours after the inflation the dog appeared to be in perfect health. The normal relations in the chest had become restored and the subcutaneous emphysema was less extensive. The animal was kept under observation for a considerable length of time, but at no time could symptoms of pleuritis be detected.

c.—Subcutaneous Cellular Tissue.

Experiment 55.—Old dog, weight 43 lbs. A small perfectly aseptic trocar was inserted through the skin into the loose cellular tissue in the right inguinal region and through the cannula two litres of gas were injected, the gas distributing itself through the loose connective tissue over a large surface of the body. Upon the withdrawal of the cannula the puncture was hermetically sealed with iodoform collodium and cotton. The subcutaneous emphysema disappeared completely in forty-eight hours, and no traces of inflammation could be found at the point of puncture, or at any place where the gas had come in contact with the tissues.

Experiment 56.—Dog, weight 25 lbs. Subcutaneous inflation of two litres of hydrogen gas through the cannula of a small trocar into the left side of the chest. The subcutaneous emphysema reached from the clavicle and axilla on that side to the crest of the ilium, the gas at some points elevating the skin at least four inches from the subjacent tissues. The gas was absorbed somewhat more slowly than in the preceding experiment, but three days after the inflation no trace of emphysema could be detected and the subcutaneous connective tissue was as pliable and movable as before the inflation.

V.—RECTAL INSUFFLATION OF HYDROGEN GAS IN THE
DIAGNOSIS OF PENETRATING GUNSHOT WOUNDS
OF THE ABDOMEN.

In these experiments the animals were strapped on one of Pasteur's operating tables. Abdomen shaved, and after complete etherization the shooting was done at short range with a thirty-two calibre revolver. Inflation of hydrogen gas was practiced immediately after the shot was fired, and after its diagnostic value was carefully studied the abdomen was opened and its contents examined for visceral injuries. In all cases where the colon was perforated inflation could be done under very slight pressure, as the gas readily escaped into the peritoneal cavity, and from there through the bullet wound in the abdominal wall, where it was ignited as it escaped. As it is not the object of this paper to give the result of the operative treatment, the experiments will only be described in reference to diagnosis as verified by abdominal section, but in every case an attempt was made to save the life of the animal by operative treatment, and in a few instances the efforts were rewarded by success.

Experiment 57.—Dog, weight 30 lbs. The abdomen was opened by an incision through the linea alba and a coil of the small intestine was drawn forward into the wound, and an incision one-half an inch (12 mm.) in length was made on the convex side and the intestine returned. A small glass tube was inserted into lower angle of wound, and the rest of the wound closed by sutures. About two litres of hydrogen gas were inflated per rectum when the gas escaped through the glass-tube, and when ignited burned with a continuous steady blue flame as long as the inflation was continued. The wound was opened and a small quantity of gas was found in the peritoneal cavity. The whole intestinal tract below the visceral wound was found moderately distended.

by gas, while above the wound the intestine was normal in size.

Experiment 58.—Dog, weight 15 lbs. When the dog was completely under the influence of ether hydrogen gas was forced from anus to mouth, and while the abdomen was still moderately distended the animal was shot in the abdomen, the bullet being directed transversely from the point of entrance on the side of the abdomen two inches (5 cm.) to the right of the median line and on a level with the umbilicus. On applying a lighted taper to wound of entrance, and compressing the abdomen, hydrogen gas escaped and was ignited. When the inflation was resumed the gas burned with a continuous flame at the wound of entrance. The abdomen was then opened and two perforations in the stomach were found, one on the anterior surface near the pylorus, and the other on posterior surface at the cardiac extremity, about an inch above the omental attachment. The distension of the stomach by hydrogen gas had brought this organ within range of the track of the bullet.

Experiment 59.—Dog, weight 20 pounds. Under complete anæsthesia the animal was shot in the abdomen, the bullet taking the same direction as in the previous experiment, only that the track was about an inch (2.6 cm.) above the umbilicus. Immediately after the shooting hydrogen gas was inflated per rectum, and its presence in the abdominal cavity became evident by a marked tympanitis, absence of liver dulness, and later by a localized emphysema around the wound of entrance. As the pressure was continued bubbles of gas escaped, and on applying a lighted taper, ignited with a feeble explosive report. The abdomen was opened, and the stomach showed two perforations, one just above the omental attachment near the pylorus, and the other on the same level at the cardiac extremity. Little hæmorrhage, and no extravasation of contents of stomach.

Experiment 60.—Dog, weight 30 pounds. Animal anæsthetized and shot in abdomen at a range of two feet; wound of entrance two inches to the right of, and on a level with, the umbilicus. Wound of exit one inch above the middle of left crest of ilium. Inflation of hydrogen gas per rectum soon caused extensive tympanitis, and as but little force had been used the conclusion was drawn that some part of the descending colon had been injured. As the gas did not readily escape through the bullet wounds a small cannula was inserted into the abdominal cavity through the wound of entrance, when the gas escaped freely and was ignited. On opening the abdomen examination revealed the following visceral injuries: Two perforations in the descending colon, four in the ileum, within a distance of ten inches of the ileo-cæcal valve, eight in the upper part of the ileum within the space of one foot (30 cm.) of the intestine. The mesentery was perforated at three points, and a number of mesenteric vessels of considerable size were severed, which gave rise to profuse hæmorrhage.

Experiment 61.—Large coach dog. The animal was completely etherized and shot in the abdomen at close range. Wound of entrance midway between linea alba and vertebral column on left side, a little below the level of the umbilicus; wound of exit close to last lumbar vertebra over crest of ilium on opposite side. Rectal inflation of hydrogen gas under slight pressure at once produced diffuse tympanitis, and the gas escaped freely through wound of entrance where it was ignited and burned with a large steady blue flame as long as the inflation was continued. On opening the abdomen gas escaped, but inspection showed that the small intestines contained no gas, a condition which pointed to the colon as the seat of perforation. One perforation was found in the anterior wall of the sigmoid flexure and two perforations in the cæcum. In

the small intestines two perforations were found in the ileum near the cæcum, and three in the upper portion of the jejunum. Among the other organs injured were the spleen, the receptaculum chyli, and a number of perforations in the mesentery.

Experiment 62.—Large dog, profound ether narcosis. Shot in the abdomen, the bullet entering on a level with the umbilicus and about one inch to the left of the median line. Point of exit two inches from spinal column, and a little above the lower border of the chest. On inflating the rectum with hydrogen gas hardly any force was required to distend the abdomen, and for this reason it was believed that the colon in some part of its course had been injured. Gas escaped readily through the wound of entrance where it was lighted and burned with the characteristic blue flame. The abdomen when opened was found almost completely filled with blood. The source of this profuse hæmorrhage was the right kidney which showed a perforation through the centre. An examination of the gastro-intestinal canal revealed two perforations of the cæcum, and five of the small intestines. After passing through the kidney the bullet perforated the diaphragm, traversed the pleural cavity and escaped through the chest wall two inches (5 cm.) to the right of the spine.

Experiment 63.—Old dog, weight 35 pounds. Thoroughly etherized and shot in the abdomen, the bullet entering three inches (7.4 cm.) to the right of, and an inch and a half (3 cm.) below, the umbilicus, passing almost transversely through the abdominal cavity it escaped at a corresponding point on left side. Inflation of hydrogen gas was attempted, but failed on account of the apparatus being out of order. The abdomen was opened and no gas was found even in the colon. Twelve perforations of the small intestines were found, and a number of perforations

of the mesentery which had caused profuse hæmorrhage.

Experiment 64.—Large, black dog. Etherized and shot in the abdomen, wound of entrance three inches (7.4 cm.) to the right of, and an inch and a half below, the umbilicus; wound of exit near a corresponding point on opposite side, the bullet taking nearly a transverse course. Rectal inflation of hydrogen gas gave a prompt positive result. The abdomen was opened and five perforations of small intestine were found, besides laceration of thoracic duct, and a number of perforations in mesentery. Colon and small intestine below the lowest point of perforation contained gas, while above the lowest perforation the bowel contained no gas.

Experiment 65.—Dog, weight 25 pounds. Under full anæsthesia the animal was shot in the abdomen, the bullet passing nearly in a transverse direction through the abdominal cavity an inch and a half below the umbilicus from points of entrance and exit midway between linea alba and spine. Rectal insufflation of hydrogen gas made under very low pressure led to rapid distension of the abdomen, an occurrence which furnished strong evidence that the gas had escaped through a perforation in the colon into the peritoneal cavity. The gas escaped in bubbles through the wound of entrance, and when a lighted taper was held near the wound it burned with a jet varying in size. On opening the abdomen gas escaped from the peritoneal cavity, small intestines empty, and only a small amount of gas in the colon. The following intra peritoneal injuries were found: Four perforations of the duodenum, two of the jejunum, and one of the cæcum also a perforation nearly through the centre of the left kidney, laceration of the receptaculum chyli, and a number of perforations in the mesentery. The bullet was found between the left kidney and the abdominal wall.

In all of these experiments the bullet was fired

through the abdomen from side to side transversely, or somewhat obliquely, directions which invariably brought into the track of the bullet a number of intestinal coils, and often the colon likewise. In the two experiments where the track of the bullet was a little higher up the intestines escaped, but the stomach showed two perforations, one near the pyloric, and the other near the cardiac extremity. Rectal insufflation of hydrogen gas proved an infallible test in every instance, except in the case where it failed on account of the inflation apparatus being out of order. Contrary to the experience of other experimenters, I found that fæcal extravasation does not uniformly take place soon after gunshot wounds of the intestines, and in the cases where I observed it some part of the colon had been wounded. Intestinal inflation does, therefore, not tend to increase the frequency of this occurrence, and must therefore be looked upon as a harmless measure in this direction.

Inflation, as a preliminary measure, greatly expedites the first step in the operation of abdominal section in cases where the intestine has been perforated or injured, as the gas which escapes into the peritoneal cavity separates the intestines from the anterior abdominal wall, and the incision can be made safely and rapidly without fear of wounding the intestines. Penetrating wounds of the abdomen, where the course of the bullet is in an opposite direction to that which has been described in the preceding experiments, that is in an antero-posterior direction, may not implicate the intestines at all, or if visceral injury is inflicted, it is more likely that only a single perforation exists, and never does the surgeon meet with such a multiplicity of lesions as have been cited above. Unless the surgeon can ascertain before hand that in a case of penetrating wound of the abdomen an injury to some portion of the gastrointestinal canal exists, the very means which he re-

sorts to in making an anatomical diagnosis is often an imminent source of danger, as only too often he may have to examine every inch of the gastro-intestinal canal for this purpose, a procedure which is always attended by great risk to life. If by such a simple and harmless procedure as insufflation of hydrogen gas he can satisfy himself that the gastro-intestinal canal is perforated, the course to pursue becomes clear—to open the abdomen, *seek for the perforation until he finds it*, and to adopt proper treatment for the visceral injury.

Cases have also happened in which the operator opened the abdomen, sought for, found and treated one or more perforations, and on making the autopsy a day or two later found, to his great chagrin and sorrow, a perforation which he had overlooked at the time of operation. It seems to me that in cases in which any doubt exists as to the integrity of the remaining portion of the intestinal canal, after closing one or more perforations, it would be advisable to search for additional perforations by resorting again to slow and careful inflation before the abdominal wound is closed. If no other perforations exist the gas will be confined to the interior of the gastro-intestinal canal, and if the stomach or intestines at some point difficult of access are injured, the leakage of gas through the perforations will lead the surgeon to the wound.

In the practical application of rectal insufflation of hydrogen gas, as a means of diagnosis in penetrating wounds of the abdomen, the field of possible operation should be carefully prepared by shaving and disinfection before inflation. After thorough disinfection of the external wound or wounds, and the field of operation, the patient should be placed thoroughly under the influence of an anæsthetic for the purpose of relaxing the abdominal muscles, which greatly facilitates the inflation. In the absence of a Wolf's bottle hydrogen gas can be readily generated

in a large wide-mouthed bottle into which a small handful of chips of pure zinc is placed. The mouth of the bottle is closed with a cork with two perforations, through which two glass tubes are inserted, one for the purpose of pouring in water and sulphuric acid, and the other, which should be bent nearly at right angles, for leading away the gas. This glass tube and the rubber balloon with a capacity of 16 litres of gas are connected by means of a rubber tube. In from five to ten minutes the requisite amount of gas can be generated and everything is ready for the inflation. The rubber tube connecting the balloon with the rectal tip of an ordinary syringe should be interrupted by a stop-cock, so that the escape of gas can be prevented whenever inflation is temporarily suspended. The return of gas along the sides of the rectal tip can be readily prevented by an assistant pressing the anal margins firmly against it. The inflation must always be made *slowly, as long continued, uninterrupted pressure accomplishes most effectually lateral and longitudinal dilatation of the cæcum*, conditions which render the ileo-cæcal valve incompetent, and which must be secured before inflation of the small intestines is possible. The entrance of gas from colon into the ileum is always attended by a diminution of pressure, and its occurrence can invariably be recognized by a gurgling or blowing sound over the ileo-cæcal valve, and sometimes the sounds are sufficiently loud to be heard at some distance.

If, after inflation, abdominal distension and tympanitis be from the very first diffuse, and liver dullness has disappeared, it is a certain indication that it is due to the presence of gas in the peritoneal cavity, and not to distension of the gastro-intestinal canal. If, on the other hand, the distension and tympanitis follow the course of the colon, and after the entrance of the gas through the ileo-cæcal valve is circumscribed and limited to the umbilical and hypogastric

regions, and gradually extends to the upper portion of the abdomen, *and the liver dulness is displaced upwards*, it is in all probability caused by a gradual and successive inflation of the intact bowel in an upward direction. In some penetrating wounds of the abdomen it is difficult, if not impossible, to follow the course of the bullet through the abdominal wall with a probe or finger on account of a relative change of position of the different layers of tissues in the track of the bullet obliterating the canal, but even in these cases a moderate distension of the peritoneal cavity by an accumulation of gas outside of the intestines will force bubbles of gas through the tortuous canal, and by this sign the surgeon may know positively that some portion of the gastro intestinal canal has been perforated, and in order to prove that the bubbles which escape are part of the hydrogen gas which has been inflated he applies a lighted match or taper, and if it is hydrogen gas it will ignite with a slight explosive report, and burn with a characteristic blue flame. The burning of the escaping hydrogen gas on the surface of the external wound is a most effective means in securing for the wound an aseptic condition, and on that account the escaping gas should be lighted both for diagnostic and therapeutic purposes in all cases in which rectal insufflation of hydrogen gas reveals the presence of visceral injuries of the gastro-intestinal canal.

As the hydrogen gas from its low specific gravity will always occupy the highest space in a cavity partially filled with fluids, it is necessary to place the external abdominal wound in such a position that blood or any other fluid that may be present in the abdominal cavity will not interfere with its ready escape. If the wound is anterior the patient must be placed in dorsal position; if lateral, on the opposite side during the inflation. If during inflation early and diffuse tympanitis takes place, it speaks in favor of perforation of the colon.

Should the external wound prevent the escape of gas from the peritoneal cavity by sliding of the different layers of tissue of the wound in the abdominal wall, or by the presence of a coagulum in the track made by the bullet, it becomes necessary to secure a sufficient degree of patency of the wound for the escape of gas by careful probing or the removal of coagulated blood. The finding of perforations is also greatly facilitated by inflation, as the bowel below the lowest perforation will always be found at least slightly dilated by gas. If this perforation is now closed and additional perforations are suspected to exist the inflation can be repeated, and the bowel will again become distended as far as the next perforation, and this process can be repeated until the entire intestinal canal has been examined by this method. By searching for leaking points in this manner but little manipulation of the intestines becomes necessary, and thus one of the great sources of danger in the operative treatment of wounds or perforations of the gastro-intestinal canal is avoided. The moderate distension of the intestines left after treating the visceral wounds never interfered with the return of the intestines into the abdominal cavity or the closure of the external wound in any of the experiments, and the numerous observations made in reference to the disappearance of the gas by absorption, or escape through the natural outlets, are conclusive in showing that the distension due to the presence of the gas disappears in a remarkably short time, and it can therefore be safely stated that rectal insufflation of hydrogen gas in the diagnosis and treatment of penetrating wounds of the abdomen does not interfere with an *ideal* healing of the visceral and laparotomy wounds. After a careful study of the subject of rectal insufflation of hydrogen gas in its various aspects, I do not hesitate to recommend its adoption in practice as an infallible diagnostic test in demonstrating the existence of a wound of the

gastro-intestinal canal in penetrating wounds of the abdomen or perforations from any other cause, without resorting to an exploratory laparotomy. In conclusion I beg leave to submit for your discussion the following propositions:

1. The entire alimentary canal is permeable to rectal insufflation of air or gas.

2. Inflation of the entire alimentary canal from above downwards through a stomach tube seldom succeeds, and should therefore only be resorted to in demonstrating the presence of a perforation or wound of the stomach, and for locating other lesions in the organ or its immediate vicinity.

3. The ileo-cæcal valve is rendered incompetent, and permeable by rectal insufflation of air or gas under a pressure varying from one-fourth of a pound to two pounds.

4. Air or gas can be forced through the whole alimentary canal from anus to mouth under a pressure varying from one-third of a pound to two pounds and a half.

5. Rectal insufflation of air or gas to be both safe and effective must be done very slowly and without interruptions.

6. The safest and most effective rectal insufflator is a rubber balloon large enough to hold 16 litres of air or gas.

7. Hydrogen gas should be preferred to atmospheric air or other gases for purposes of inflation in all cases where this procedure is indicated.

8. The resisting power of the intestinal wall is nearly the same throughout the entire length of the canal, and in a normal condition yields to diastaltic force of from eight to twelve pounds of pressure. When rupture takes place it either occurs as a longitudinal laceration of the peritoneum on the convex surface of the bowel, or as multiple ruptures from within outwards at the mesenteric attachment. The

former result follows rapid, and the latter slow, inflation.

9. Hydrogen gas is devoid of toxic properties, non-irritating when brought in contact with living tissues, and is rapidly absorbed from the connective tissue spaces and all of the large serous cavities.

10. The escape of air or gas through the ileo-cæcal valve from below upwards is always attended by a blowing or gurgling sound, heard most distinctly over the ileo-cæcal region and by a sudden diminution of pressure.

11. The incompetency of the ileo-cæcal valve is caused by a lateral and longitudinal distension of the cæcum which mechanically separates the margins of the valve.

12. In gunshot or punctured wounds of the gastrointestinal canal insufflation of hydrogen gas enables the surgeon to demonstrate positively the existence of the visceral injury without incurring the risks and medico-legal responsibilities incident to an exploratory laparotomy.

